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Andrew McLean and Phillip Box

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Aeronautical and Maritime Research Laboratory

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ABSTRACT

Air blast pressures resulting from the detonation of explosives are measured using air blast transducers. These transducers require calibration to ensure that air blast records from explosive experiments are accurate and traceable to recognised standards.

This paper details a calibration system and methodology for low range air blast pressure transducers

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Executive Summary

When conducting explosives experiments, transducers are used to measure air blast pressures. The accuracy of these transducers is ensured by regular calibration using equipment which has in turn been calibrated to NATA certification.

A PCB Dynamic Pressure Calibrator was acquired to calibrate pressure transducers up to a pressure of 800 kPa. A modification incorporating an electrically operated solenoid valve generates highly repeatable results.

Calibration accessories have been manufactured that allow the associated transducer electronics to be calibrated. A calibration procedure and software have been developed which enables the transducer sensitivities to be easily calculated and results archived on a computer database.

Using this equipment, software and procedures accurate and traceable sensitivities are maintained for all pressure transducers with a dynamic range up to 800 kPa.

Contents

1. Introduction

A primary result of the detonation of explosives is the propogation of a pressure pulse known as air blast. The measurement of air blast pressures is accomplished using specifically designed pressure transducers. These are robust transducers using either piezoelectric or peizoresistive technologies to generate electrical signals proportional to the pressures to which they are subjected.

The sensitivity of the transducer is the inherent property that must be known for the accurate interpretion of the electrical signals. It can be defined as the ratio of the voltage produced by the transducer, to the pressure to which it is subjected. The sensitivity of blast transducers can vary over time. The transducers therefore need to be calibrated periodically, with reference to recognised standards. In Maritime Platforms Division, blast transducers are calibrated prior to each experiment on which they are used.

This paper describes a commercially available calibration system, its operation, and how MPD uses this system to calibrate blast transducers.

2. Dynamic Pressure Pulse Calibrator System

The PCB Dynamic Pressure Pulse Calibrator, depicted in Figure 1, is used for pressure calibrations up to 700 kPa. The component parts are described below.

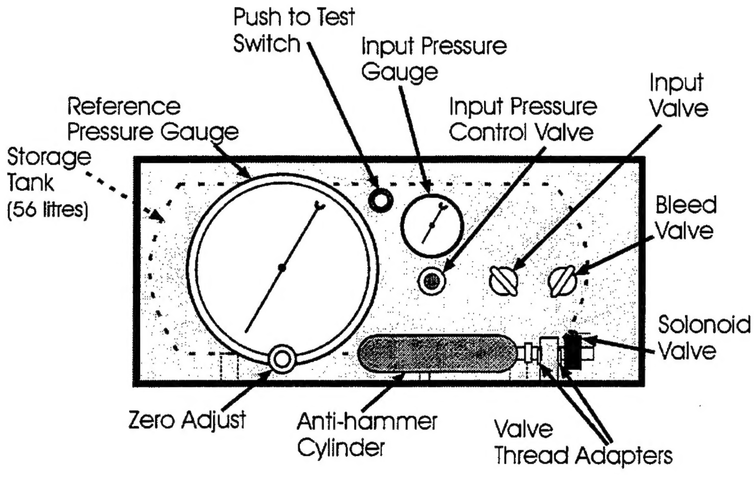

Figure 1: The PCB Dynamic Pressure Pulse Calibrator Model 903A02.

2.1 The Input Pressure Control Valve

The input pressure control valve is used, in conjunction with the Input Pressure Control Gauge, to set the maximum supply line pressure into the calibration system.

2.2 The Input Pressure Control Gauge

The input pressure control gauge indicates the air pressure in the supply line as set by the "Input Pressure Control Valve" and has a range up to 1100kPa.

2.3 Input Valve

The input valve is used in conjunction with the reference gauge to set the test pressure in the storage tank.

2.4 The 56 litre Storage Tank

The 56 litre storage tank acts as the main reservoir of air for the pulse calibrator. The "Input Valve" sets the pressure of air in the tank. The volume of this tank is very large in comparison to the manifold. *(see 2.10)* In this way insignificant airflow is required for the calibration of transducers.

2.5 Reference Gauge

The Reference Gauge is a calibrated Heise Model CM-55753 Bourdon tube gauge. The tube is manufactured by the Heise plant of Dresser Industries of Newtown Connecticut USA. This type of gauge utilises the effect of internal air pressure on a tube, which is oval in cross-section and bent into a circular arc. An increase in internal pressure serves to straighten the tube. Movement of the free end of this tube is transmitted via a linkage to a pointer, which moves around a graduated dial to indicate pressure.

The gauge's dial has a mirrored surface, to avoid parallax errors, with pressure graduations of 0.2 psi over a range of 0 - 150 psi. This allows the pressure to be read to an accuracy of 0.1%. The dial face can be rotated to ensure it reads 0.0 psi when the system is totally vented to the atmosphere. Since the calibration system is dependent on the accuracy and traceability of this gauge, MPD regularly has this gauge NATA certified. (National Association of Testing Authorities, which include the requirements of ISO/IEC guide 25-1990 and are traceable to Australian national standards)

2.6 Bleed Valve

The bleed valve is used in conjunction with the reference gauge to lower the air pressure in the storage tank. It is also used to lower the storage tank pressure to ambient air pressure when the apparatus is not being used.

2.7 The Anti-Hammer Tank

The anti-hammer tank prevents the development of shock waves from the operation of the solenoid valve. It is mounted in-line between the storage tank and the solenoid valve.

2.8 The Solenoid Valve

The solenoid valve was an addition to the previously manually operated calibrator. The valve that was used to switch the pressured air to the transducers. Different pressure–time profiles could be obtained by switching the valve at different speeds. The electrically operated solenoid obviates this problem by providing a very repeatable signal.

The solenoid valve provides for the fast switching of the air supply through to the manifold to provide a pulse of high-pressure air for the transducer(s). It switches the manifold from the atmosphere to the storage tank. In this way a pressure step equivalent to the pressure in the storage tank is subjected to the diaphragms of the blast transducers, mounted in the manifold.

2.9 The Solenoid Switch

The solenoid switch is an instantaneous push-to-make switch. It switches the solenoid valve open (switches from atmosphere to storage tank) while pressed.

2.10 The Manifold

The manifold is the interface between the transducers and the air supply via the solenoid valve. Thread adaptors may be fitted to either side, allowing the calibration of two transducers simultaneously.

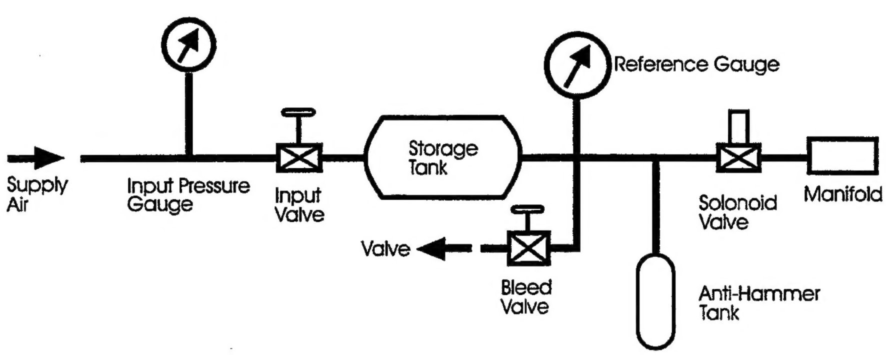

Figure 2: Schematic of the component parts of the PCB calibrator.

2.11 Transducer Thread Adaptors

The transducer thread adaptors allow the mounting of transducers with a variety of thread diameters to the manifold. They include a blank plug for use when only one transducer is being calibrated.

3. Equipment for Calibration

The electronics involved in the calibration of the blast transducer are similar to that when they are used for blast measurement. In its basic form, as depicted in Figure 3(a), a transducer is connected to an amplifier via a length of cable. The amplifier is connected to some form of electronic recording instrumentation, which digitises and stores the signal. In some cases the amplifier is an integral component of the recording instrumentation. The recording system also needs to be calibrated, with reference to a recognised standard, as shown in figure 3(b).

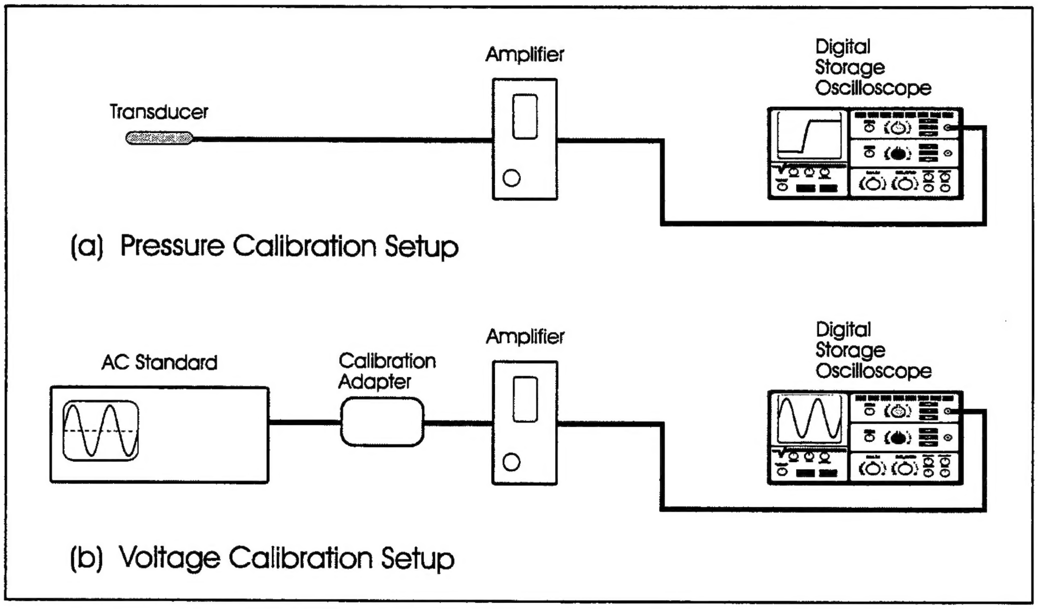

Figure 3: Connection layout for calibrations

In order to calibrate the electronics the transducer is replaced with a small passive circuit that allows an electrical signal of known amplitude to be connected in place of

the transducer. This electrical signal is generated by an A.C. standard[1] that MPD regularly has NATA certified. The calibration circuit is shown in Figure 4.

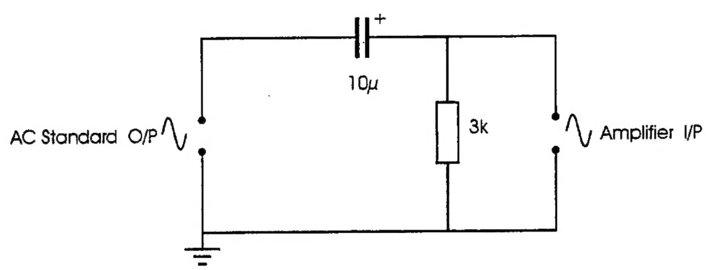

Figure 4: Calibration Adapter Circuit

The A.C. Standard is set to produce a sine wave signal e.g 1.0 V_{RMS} at 1 kHz. The signal is recorded and the amplitude measured. For a signal of 1.0 V_{RMS} at 1 kHz, and an amplifier gain of 1, the output voltage measured on the Digital Storage Oscilloscope (DSO), (V_{PP}) should be:

$$\begin{aligned} V_{PP} &= V_{RMS} \times 1.414 \times 2 \times gain \\ &= 1.0 \times 1.414 \times 2 \times gain \\ &= 2.828\,V \end{aligned}$$

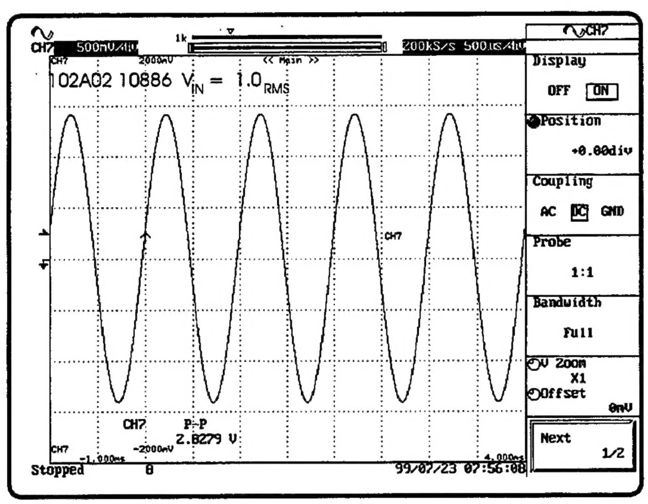

Figure 5: DSO Record of a Signal from the AC Standard

An AC Standard is an electronic device which provides a very accurate AC electrical signal of a selectable magnitude and frequency.

The signal recorded may differ from the calculated value due to inaccuracies in the amplifier or the Digital Storage Oscilloscope (DSO). The voltage measured is recorded along with the A.C. Standard output voltage and the amplifier gain. This information will be used to correct the measured readings for the calibration according to the following formula:

$$V_{CORRECTED} = V_{MEASURED} \times \left(\frac{V_{CAL} \times 2.828 \times gain}{V_O} \right)$$

Where:

V_{CAL}	is the RMS voltage set on the AC Standard
V_O	is the measured peak-to-peak voltage of the sinewave recorded on the DSO
$V_{MEASURED}$	is the pressure step votage reading from the DSO
$V_{CORRECTED}$	is the corrected value of the pressure step voltage

In the calibration process, a DSO is used to calibrate the transducer in conjunction with a signal conditioner. In the field, the Digistar ® digital data recorders provide signal conditioning and data recording. Calibration of the Digistars is decribed in another paper [1]. The influence on the transducer signal due to the resistance of long cable runs (up to 1.5 kms) has proved negligible due to the high input impedence (1MΩ) of the Digistars.

4. Calibration Procedure

The calibration procedure is based on the procedures outlined in the PCB Model 903A02 Dynamic Pressure Calibrator Operating Instructions [2]. The transducers to be calibrated are fitted to the manifold using the appropriate thread adaptors. If only one transducer is to be calibrated, a plug is fitted to the second transducer position. The end of the transducer needs to be flush with the bottom of the thread adaptor as shown in Figure 6 to ensure laminar flow across the surface of the transducer.

Teflon tape is applied to the threads of the transducers and thread adaptors to ensure a good seal.

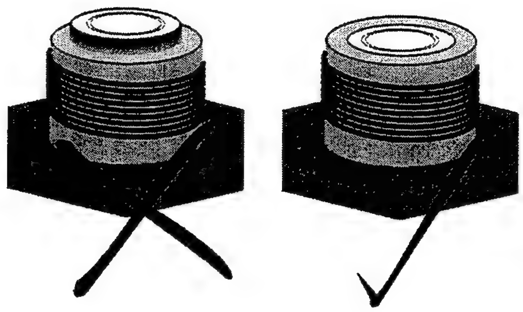

Figure 6: Correct positioning with the end of the transducer flush with the base of the thread adaptor.

An air supply is connected to the Calibrator from either bottled air or from the laboratory's air pressure lines.

The maximum air calibration pressure plus a margin is set using the "Input Pressure Control Valve". If the maximum calibration pressure were to be 700 kPa then the maximum would be set at around 800 kPa. The extra margin allows the maximum pressure to be achieved more quickly when setting the pressure on the reference gauge with the "Input Valve".

Before filling the storage tank, the reference gauge is adjusted to show zero at ambient pressure. This is done with the bleed valve opened to ensure the tank is at ambient pressure.

The calibration procedure consists of three pressure steps at each of at least four pressure levels between zero and the nominal range of the transducer. For example a 100-psi transducer is calibrated at 20, 40, 60, 80, and 100psi. As the reference gauge is manufactured in the USA, the markings are in psi. As a consequence, the calibrations are performed in psi and the sensitivities are then calculated in both mV/psi and mV/kPa. The input valve and the bleed valve are used to accurately set the desired pressure by monitoring the reference gauge, for the calibration step.

Figure 7 shows the complete waveform recorded from a transducer. It exhibits the sharp rise time and the start of exponential decay of the signal according to the time constant of the transducer. The curve drops away upon the release of the test button, which returns the manifold to atmospheric pressure.

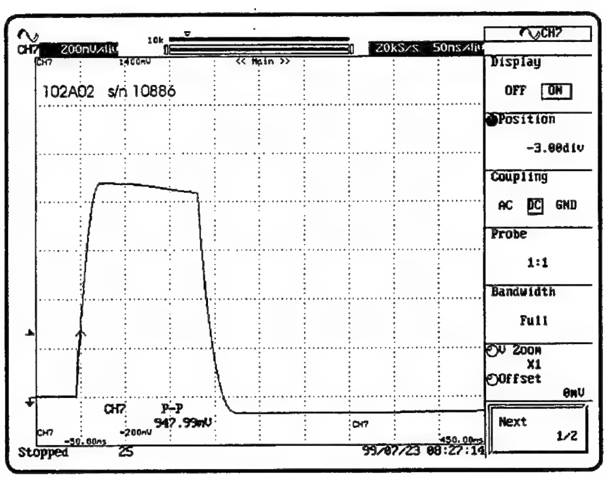

Figure 7: Complete test waveform recorded on DSO

For the calibration process, the DSO is configured to utilise as much as possible of its dynamic range, and therefore utilise as much of the digital resolution as possible. The DSO is used in a single-shot mode and is triggered using the pressure step signal. The pre-trigger facility of the DSO is used to position the pressure step so a measurement can be taken from the baseline of the pressure signal prior to the pressure step to the maximum signal level, as shown in Figure 8.

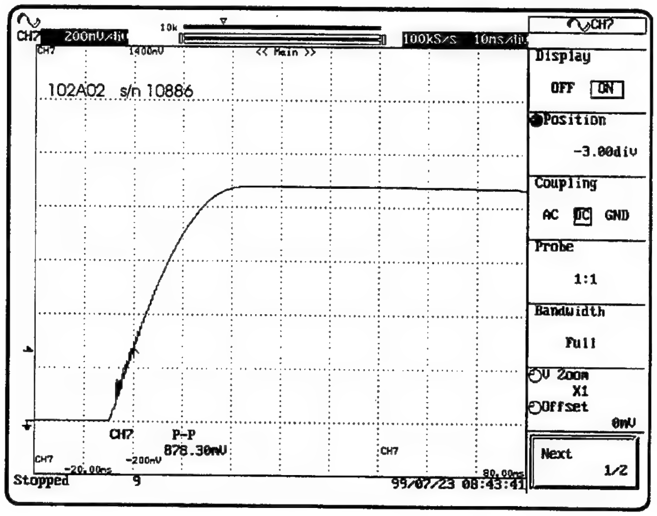

Figure 8: DSO record of a waveform optimised for accurate measurement

The calibration steps have proved extremely repeatable with any variation due to the digitisation steps of the DSO. The DSO is an 8-bit device so the digitisation error is therefore :

$$\frac{1}{256} \times 100 = 0.39\% \text{ or } \pm 0.4\%$$

5. Calibration Analysis

A spreadsheet in Microsoft Excel allows straightforward processing of the calibration results to provide a sensitivity for the transducer and confirm its linearity across the operational range.

The software prompts the user for basic details about the calibration process, (see Figure 9) before providing the Excel spreadsheet. The spreadsheet requires user input in order to calculate the transducer sensitivity. (see Figure 10)

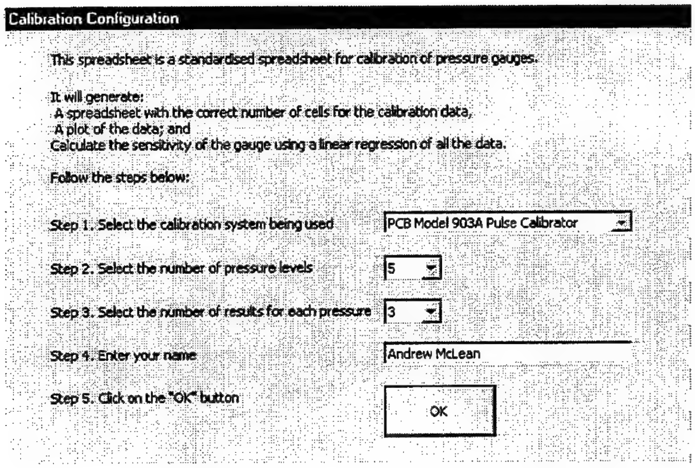

Figure 9: Opening screen of calibration software

The transducer model number, serial number, A.C. Standard V_{OUT} and the $V_{MEASURED}$ from the voltage calibration are entered. The calibration pressure levels, calibration measurements and amplifier gain, are entered in the columns provided. The calculation of the transducer sensitivity, in mV/psi and mV/kPa, uses the linear regression algorithm in Microsoft Excel. All of the calibration steps are included in the calculation and the resultant linear equation is not forced through zero. A graph of the results shows the linearity of the transducer across the test range and the coefficient of determination from the linear regression quantifies the linearity.

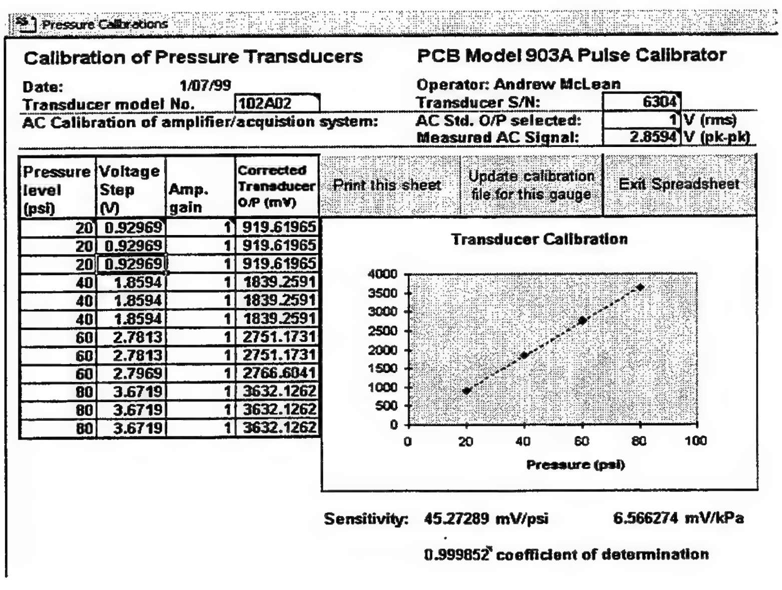

Figure 10: Calibration software main working screen

Functions provided by a series of buttons above the graph print the calibration page and write the results to a file that archives all calibrations for the transducer. This file includes all the details of the calibration and its name is derived from the transducer type and serial number.

The calibration spreadsheet and the transducer calibration files are stored on the MPD computer network.

6. Conclusion

The transducer calibration procedure as outlined in this paper produces sensitivities for transducers that are traceable to two secondary standards, these being the AC Voltage Standard and the reference pressure gauge. These two secondary standards are regularly NATA certified and as such the sensitivities of transducers are traceable to NATA standards. The calibration histories of the blast transducers in MPD are stored on the computer network and hardcopy of each individual calibration is placed on the appropriate registry file for the experiment to be conducted. This ensures accuracy and tracebility of all pressure results provided using these transducers.

7. References

[1] " Digistar III Data Recorders - Characteristic, Modifications and Performance ", Darren Wiese, Phillip Box, MRL Technical Report, 2000

[2] " Transducer Instrumentation Model 903A02 Dynamic Pressure Calibrator " Operating Instructions, PCB Piezotronics Inc, Buffalo New York USA

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Andrew McLean and Phillip Box

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